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Time-Domain Bistatic SAR Processor

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Defence R&D Canada – Ottawa

TECHNICAL MEMORANDUM
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Abstract

The Defence R&D Canada – Ottawa (DRDC Ottawa) is participating in a joint experiment with the Air Force Research Laboratory (AFRL) in Rome, New York under TTRDP. The objective of this study is to understand bistatic radar and bistatic clutter statistics, and to investigate processing methods with the ultimate aim of detecting airborne targets. As part of this study SAR processing techniques are developed for bistatic SAR data.

The data set used to test the processor in this study were acquired in Rome, NY during the trial dated 28 January 2002. The data are examined for saturation, integrity, spectral properties and phase stability. The bistatic SAR processor is coded in Matlab using time-domain azimuth compression and bistatic SAR images are produced.

Résumé

R & D pour la défense Canada – Ottawa (RDDC Ottawa) participe à une expérience en collaboration avec le Air Force Research Laboratory (AFRL) situé à Rome (New York), dans le cadre du programme TTRDP. L'étude a pour objectif la compréhension des statistiques sur le radar bistatique et sur le clutter bistatique et la recherche de méthodes de traitement dont le but ultime est de détecter des cibles aériennes. Dans le cadre de cette recherche, des techniques seront mises au point pour le traitement des données du RSO bistatique.

L'ensemble de données qui servira à mettre à l'essai le processeur utilisé dans l'étude a été recueilli à Rome (New-York), durant des essais effectués le 28 janvier 2002. Les données serviront à déterminer la saturation, l'intégrité, les propriétés spectrales et la stabilité de phase. Le processeur du RSO bistatique a été programmé en Matlab à l'aide d'un algorithme de compression d'azimut dans le domaine temporel, et des images provenant du RSO bistatique ont été produites.

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Executive summary

Bistatic radar technology has been developed since the early 80's. Recently, in order to develop space based bistatic surveillance systems, several programs were initiated. In these surveillance systems, the illuminator will be in orbit, and UAV based receivers will fly close to the battle area of interest. The system will be tasked with either AMTI (Air Moving Target Indication) or the GMTI (Ground Moving Target Indication) missions, or both.

In order to achieve AMTI, bistatic radar and bistatic clutter statistics were examined. In 2002 and 2003, several TTRDP trials were executed in cooperation between Air Force Research Laboratory (AFRL) and DRDC Ottawa, to collect bistatic radar data, where RADARSAT-1 is used as illuminator and a rooftop static receiver antenna is used as receiver. Some sets of these data were analysed in DRDC Ottawa's Radar Applications and Space Technology (RAST) and Radar Systems (RS) sections, and a bistatic SAR processor has been coded in Matlab©.

The algorithm used for azimuth compression is a time domain algorithm, where the satellite locations are required at the exact transmission time of each pulse. For this purpose, the so-called Satellite Tool Kit (STK) is used. The Earth-centered Cartesian coordinates of the satellite locations are predicted by using STK.

Results show that it is possible to produce good images by using time domain processing for bistatic synthetic aperture radar. However, timing information is crucial to predict the satellite locations. The trial geometry is also very important to get an image without ambiguities. The receiving antenna must be looking towards an area where constant Doppler lines and range ellipsoids are nearly perpendicular to each other.

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Sommaire

La mise au point de la technologie de radar bistatique remonte au début des années 80. Récemment, en vue de développer des systèmes spatiaux de surveillance bistatiques, plusieurs programmes ont été lancés. Dans ces systèmes de surveillance, l'illuminateur est en orbite, et des récepteurs sont placés à bord d'engins télépilotés qui survolent de près la zone de combat d'intérêt. Le système reçoit soit une mission d'indication de cibles aériennes mobiles (AMTI), soit une mission d'indication de cibles terrestres mobiles (GMTI), ou les deux missions.

Afin d'effectuer l'AMTI, on a examiné les statistiques sur le radar bistatique et sur le clutter bistatique. En 2002 et en 2003, le Air Force Research Laboratory (AFRL) et RDDC Ottawa ont mené en collaboration plusieurs essais TTRDP afin de recueillir des données sur le radar bistatique, dans lesquels le satellite RADARSAT-1 avait été utilisé comme illuminateur, et une antenne de réception statique de toît avait été utilisée comme récepteur. Certains ensembles de données recueillis ont été analysés par la section d'applications radar et de technologie spatiale et par la section des systèmes radar de RDDC Ottawa, et un processeur RSO bistatique a été programmé en Matlab©.

L'algorithme utilisé pour la compression d'azimut est un algorithme à domaine temporel, dans lequel l'emplacement des satellites au moment exact de la transmission de chaque impulsion doit être connu. À cette fin, on utilise le logiciel STK (Satellite Tool Kit). Le STK sert à établir les coordonnées cartésiennes par rapport à la Terre pour l'emplacement des satellites.

Les résultats indiquent qu'il est possible de produire des images de bonne qualité en utilisant des techniques de traitement à domaine temporel pour radar à synthèse d'ouverture bistatique. Cependant, les données temporelles sont cruciales pour déterminer l'emplacement des satellites. La géométrie d'essai est également très importante afin d'obtenir une image sans ambiguïté. L'antenne de réception doit être dirigée vers un emplacement où les lignes Doppler constantes et les ellipsoïdes de distance sont mutuellement quasi perpendiculaires.

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Acknowledgments

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The authors would like to thank the colleagues from AFRL in Rome for their excellent work done during the experiments and in preparation of the data sets.

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1. INTRODUCTION

Defence R&D Canada – Ottawa (DRDC Ottawa) is participating in a joint experiment with the Air Force Research Laboratory (AFRL) in Rome, New York. The objective of this study is to understand bistatic radar and bistatic clutter statistics, and to investigate processing methods with the ultimate aim of detecting airborne targets.

As a part of this project, a time domain bistatic SAR processor is developed. The processor uses Satellite Tool Kit (STK) predicted satellite locations to calculate the expected signal received by the receiver antenna. The antenna locations are known in the geodetic coordinates, so a geodetic-to-Cartesian coordinate transformation is done. The Earth's rotation is also included in the calculations.

The processor is written in Matlab©.and in order to make the processing faster, an in-beam mode is also implemented. For post processing, several tools are coded, such as; equi-distance and equi-Doppler contours, geodetic locations, sinc-filter, and distance calculations.

The timing information is calculated from the direct path data and thus STK predicted locations are aligned with the measured data. The processor is tested with simulated and real data. The results show that processor works well and the images contain valuable information.

DRDC Ottawa initiated work on the time domain processor in 2002 [1]. Some initial analysis of the 28 January 2002 data set was performed and a contract to further investigate the data sets and to develop a first version of a time domain bistatic SAR processor was given to Vantage Point International Inc. (VPI) [2]. VPI developed the processor in Microsoft Visual C++.

In parallel, DRDC approved a Technology Investment Fund (TIF) project on the development of an experimental airborne bistatic SAR system in 2003 [4]. The here developed time domain processor will be integrated into this project, and as a result the algorithm has been improved, with respect to computation time and the use of post processing tools to overcome ambiguities.

2. PRE-PROCESSING WITH STK

The time domain bistatic radar processor uses the satellite locations to calculate the expected signal received by the receiver antenna. STK is used to predict these locations.

In STK, the receiver location is inserted as a facility object with geodetic coordinates of the receiver antenna and satellite is inserted by choosing the TLE file of that day. The TLE file number for the RADARSAT-1 is 23710 as shown in the Figure-1 below.

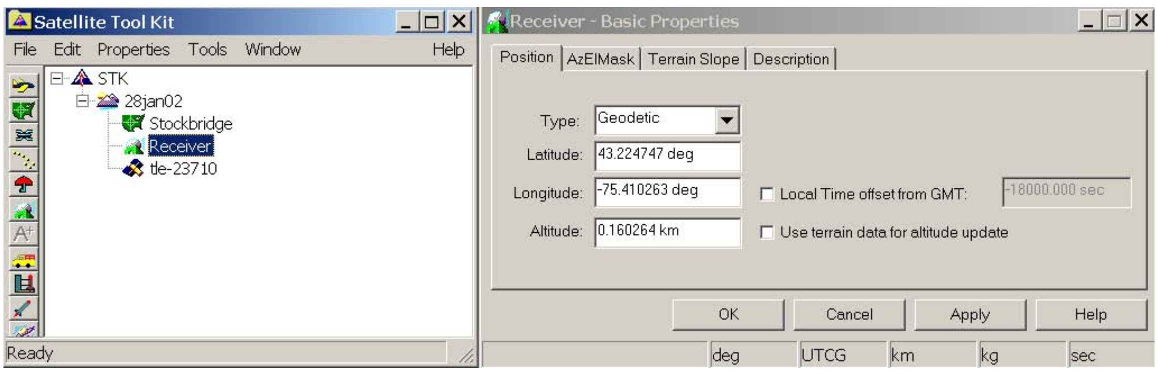

Figure 1. STK scenario objects

The processor uses two kinds of information from STK; First, the satellite locations and the second, the timing information for alignment. In order to get the correct satellite locations, the corresponding time interval when the satellite is passing by the receiver must be selected. The 2D & 3D graphic windows are used for this purpose as shown in Figure-2.

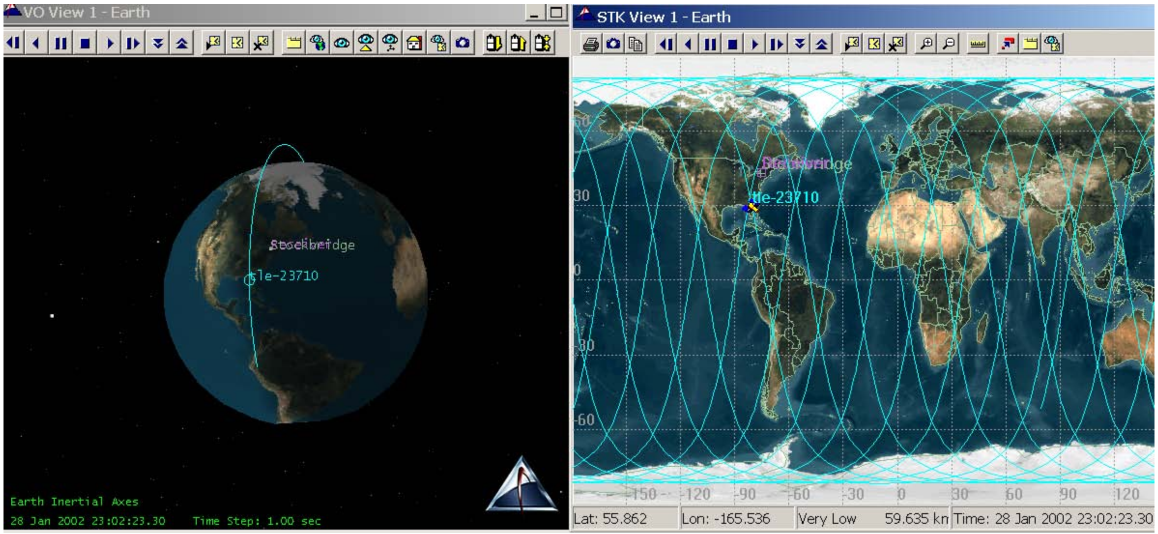

Figure 2. 2D & 3D Graphics windows

By using the report tool for satellites, a new report style is created, which contains satellite locations and velocities in Cartesian coordinates. In Figure 3, the contents of the report style are shown. The time period for the report must be identical to the time interval found from the graphics windows and the step size/time bound must be adjusted to 0.01 seconds/None. The created report is exported as a '.csv file' and can be read, for instance, by using MS-Excel. The .csv file is converted to a tab delimited text file, which then can easily be loaded into Matlab©.

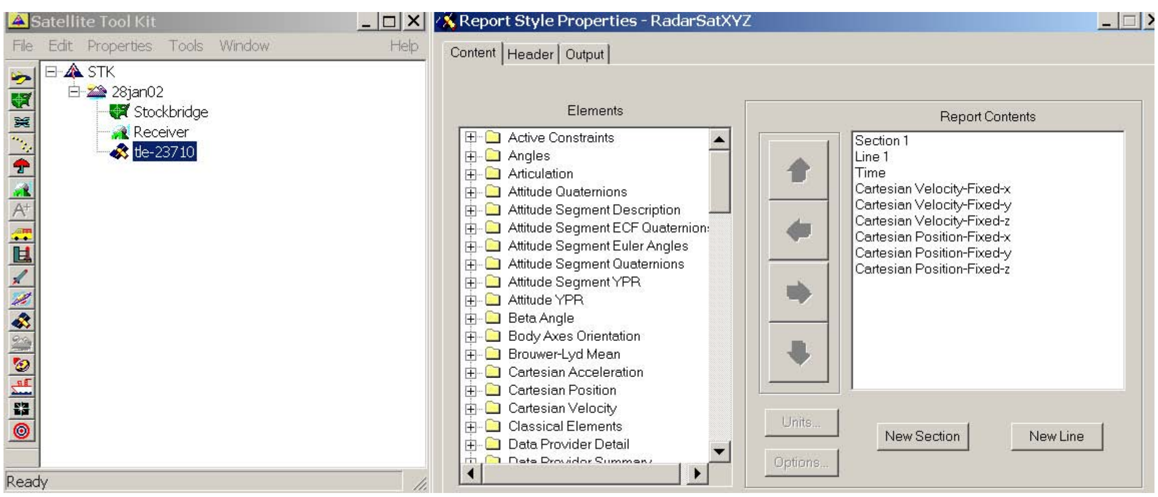

Figure 3. Report style contents

The alignment of the measured data with the STK predicted satellite locations is achieved by defining a sensor with the RADARSAT properties and getting the Access time when the sensor is orthogonal to the receiver antenna. Figures 4 and 5 shows the sensor properties and Access report where the azimuth is 90 degrees. The Access report is created as a custom report with the time period being the same as the report for satellite locations. The time found from the Access report is used to align the measured data to the point in time where the maximum magnitude occurs.

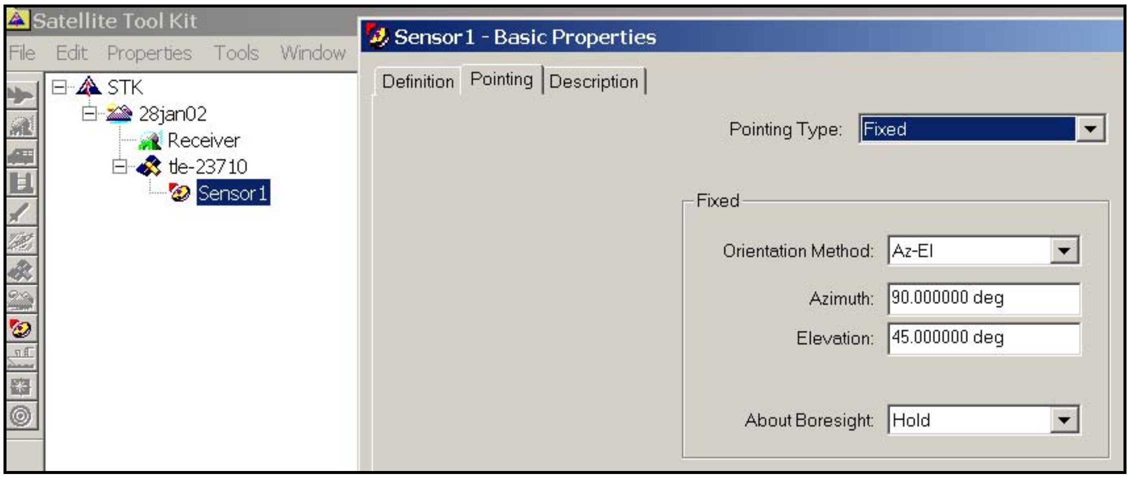

Figure 4. Sensor properties

More information about the usage of STK can be found in Analytical Graphics STK Training Manuals. [3]

06 Jul 2004 11:30:46
Satellite-tle-23710-Sensor-Sensor1-To-Facility-Receiver: Inview Azimuth, Elevation, & Range

Sensor1-To-Receiver

Time (UTCG)	Azimuth (deg)	Elevation (deg)	Range (km)
28 Jan 2002 23:06:00.27	89.966	-48.828	1115.991408
28 Jan 2002 23:06:00.28	89.971	-48.828	1115.993815
28 Jan 2002 23:06:00.29	89.976	-48.828	1115.996226
28 Jan 2002 23:06:00.30	89.981	-48.828	1115.998642
28 Jan 2002 23:06:00.31	89.986	-48.828	1116.001063
28 Jan 2002 23:06:00.32	89.991	-48.828	1116.003488
28 Jan 2002 23:06:00.33	89.997	-48.827	1116.005917
28 Jan 2002 23:06:00.34	90.002	-48.827	1116.008351
28 Jan 2002 23:06:00.35	90.007	-48.827	1116.010790
28 Jan 2002 23:06:00.36	90.012	-48.827	1116.013232
28 Jan 2002 23:06:00.37	90.017	-48.827	1116.015680
28 Jan 2002 23:06:00.38	90.022	-48.827	1116.018131
28 Jan 2002 23:06:00.39	90.028	-48.827	1116.020587
28 Jan 2002 23:06:00.40	90.033	-48.827	1116.023048
28 Jan 2002 23:06:00.41	90.038	-48.826	1116.025513
28 Jan 2002 23:06:00.42	90.043	-48.826	1116.027983

Figure 5. Access report

In order to match the satellite locations with the measured data, the time at which the minimum distance from the satellite to receiver antenna occurs, is also calculated. Figure 6 shows the calculated distance for 28 Jan 2002 data set.

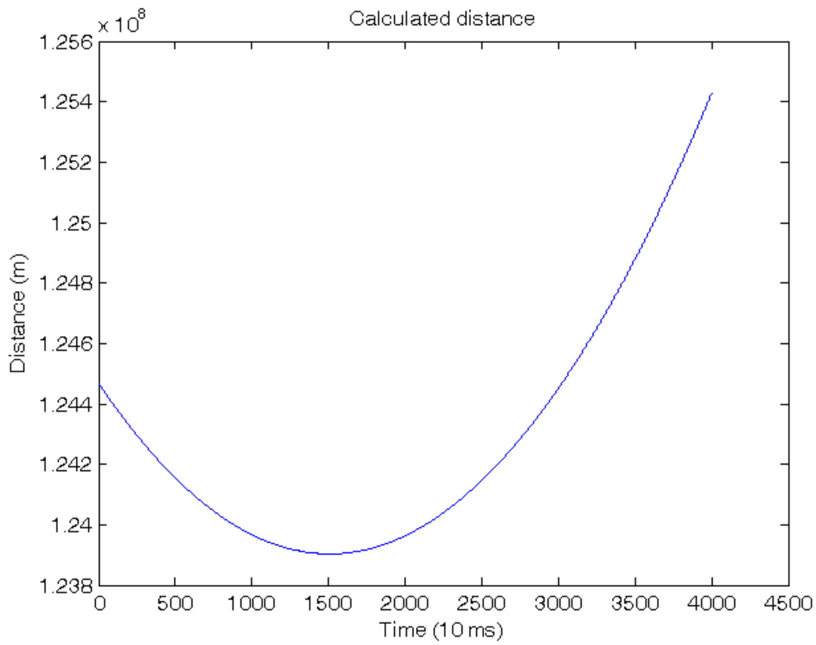

Figure 6. Distance calculated from STK data

3. PEAK AMPLITUDE LOCATION

The sample number of the maximum amplitude peak is used for the purpose of aligning the measured data with the STK predicted satellite locations. The processor comprises a subroutine to calculate the maximum peak amplitude and also to plot the transmitter antenna pattern and the phase history, as shown in Figure 7. This subroutine can be initiated from a scenario file. A sample scenario file is given in Appendix-A.

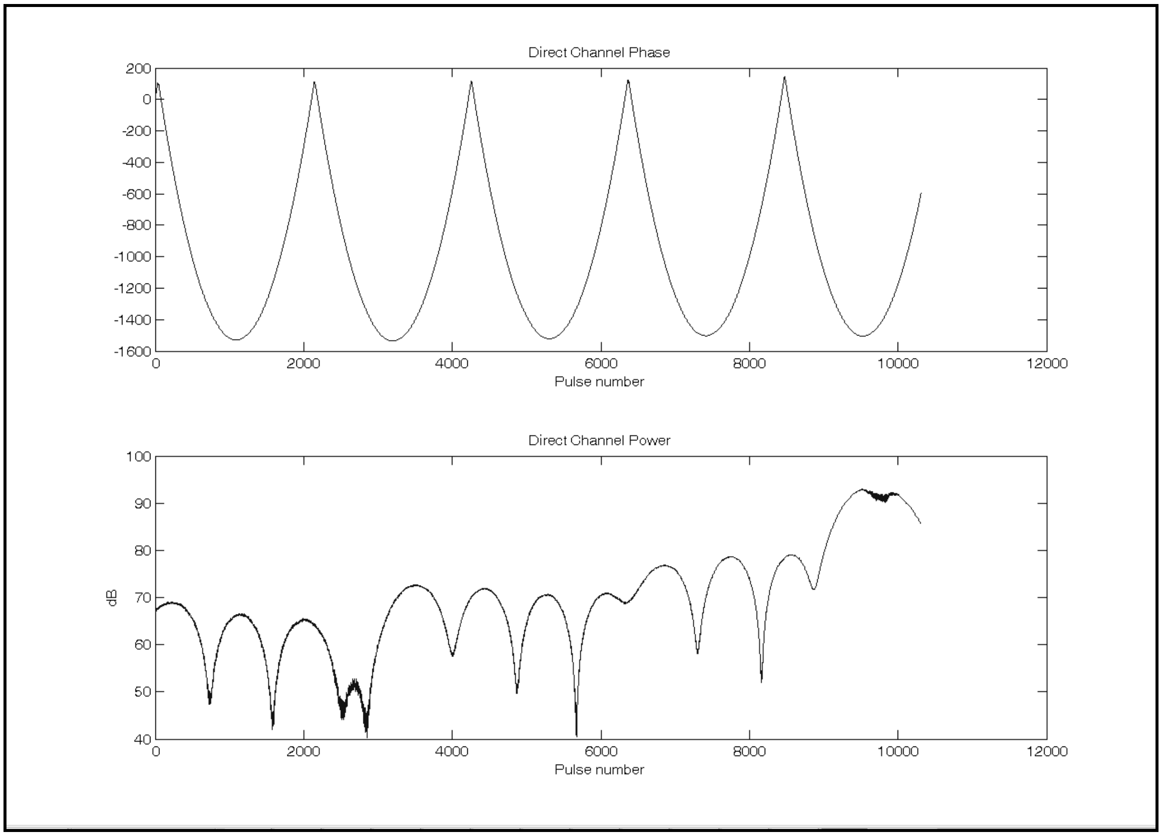

Figure 7. Transmitter antenna pattern and phase history

4. IQ DEMODULATION AND RANGE COMPRESSION

IQ-demodulation is the first step of signal processing in the bistatic SAR processor. A classical quadrature demodulator, which is shown in Figure 8, is used for this purpose. The range compression is accomplished in the frequency domain with a matched filter for each I and Q channel.

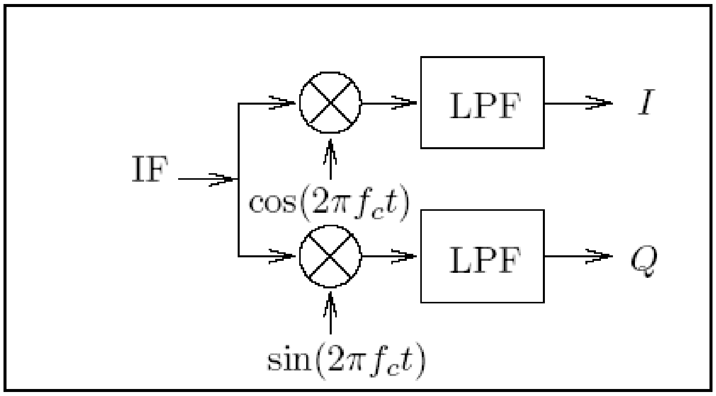

Figure 8. Quadrature demodulator

The signal transmitted by the radar is a chirp signal, which can be represented by the following formula:

$$s(t) = \exp\left(j\pi \frac{B}{t_p} t^2 \right),$$

where B denotes the chirp bandwidth and and t_p is the pulse duration. The complex conjugate of this signal is used to compress the received signal as a matched filter.

The bistatic SAR data consist of a direct channel (along the transmitter-receiver line-of-sight LOS) data set and four sub-aperture channel data sets. The direct channel is used to locate the transmitted pulse locations in the sub-aperture channels. Due to this reason, the direct channel is range compressed first. The processor uses the parameters that are defined in the scenario file to produce the matched filter and then to range compress the data. The first 30 peaks are used to measure the pulse repetition frequency (PRF). The PRF is expected to be fixed and hence, the processor does not need to handle PRF-staggering and/or agility. The measured PRF is then used to locate the peaks. Thus, a rough estimate of the PRF from the scenario file is enough for the processor to locate the pulses from the direct channel. Pulse location finding is followed by the sub-aperture range compression. From the sub apertures each range profile is aligned with the direct channel pulse locations. By using this procedure, a part of the timing information, which is necessary for time domain azimuth compression, is included in the data.

5. AZIMUTH COMPRESSION AND COORDINATE TRANSFORMATIONS

In this project, we have chosen to apply time domain azimuth compression to the bistatic data. The fundamental aspect of this approach is that it is a matched-filter implementation of time-domain correlation. For each satellite location, the expected phase for each cell is calculated and the complex conjugate of this signal is multiplied by the return from that specific cell. The pseudo-code for the time domain azimuth compression algorithm is given in the Table 1.

Table 1. Time-domain azimuth compression pseudo-code

do l = 1 to L	Loop over each satellite position
do n = 1 to N	Loop over each image cell
$R_{sc} = \sqrt{}\ ((x_s - x_c)^2 + (y_s - y_c)^2 + (z_s - z_c)^2$	Calculate satellite to cell range
$R_{ca} = \sqrt{}\ ((x_c - x_a)^2 + (y_c - y_a)^2 + (z_c - z_a)^2$	Calculate cell to antenna range
$R_b = R_{sc} + R_{ca}$	Calculate bistatic range for this cell & satellite location
$R_{sa} = \sqrt{}\ ((x_s - x_a)^2 + (y_s - y_a)^2 + (z_s - z_a)^2$	Calculate direct range from antenna to satellite location
$R_{diff} = R_b - R_{sa}$	Calculate range difference
$\theta = \exp\ [j\ (2\pi/\lambda)\ R_{diff}]$	Complex phase of the expected return echo
$index_n = R_{diff} / \Delta r$	index to locate the range cell in range profile (Δr = range between each sample in range profile)
$E_{nm}^{temp} = data(l, index_n)\ x\ conj\ (\theta)$	Generate a set of *n* x *m* pixels for each satellite position by multiplying complex conjugate of calculated phase with the measured data
end n loop	
$E_{nm} = E_{nm} + E_{nm}^{temp}$	- Coherent summation of images.
end *l* loop	

The satellite locations are calculated in Earth-centered rotating Cartesian coordinates. (In STK, Earth-centered rotating Cartesian coordinates are called Earth-centered fixed (ECF) coordinates.) The antenna locations are known in geodetic coordinates, which means that a geodetic-to-Cartesian coordinate transformation is required, using the following algorithm for antenna and ground point (imaging area) locations. By using the maximum power and minimum distance (range) locations, previously calculated in STK, and the maximum power location from the measured data, each range profile is aligned with the corresponding satellite location. These locations are then used to calculate the satellite-to-cell, cell-to-receiver and satellite-to-receiver distances, which are required to calculate the phase history.

$$X = (N + h)\cos\phi\cos\lambda$$
$$Y = (N + h)\cos\phi\sin\lambda$$
$$Z = [N(1 - e^2) + h]\sin\phi$$

where:

$\phi, \lambda, h =$ geodetic latitude, longitude, and height above ellipsoid

$X, Y, Z =$ Earth Centered Earth Fixed Cartesian Coordinates

and:

$N(\phi) = a / \sqrt{1 - e^2 \sin^2\phi} =$ radius of curvature in prime vertical

$a =$ semi-major earth axis (ellipsoid equatorial radius)

$b =$ semi-minor earth axis (ellipsoid polar radius)

$f = \dfrac{a - b}{a} =$ flattening

$e^2 = 2f - f^2 =$ eccentricity squared

It is also necessary to make an Earth rotation correction. The tangential speed v_t of the Earth for each ground point is calculated by the following formula.

$$v_t = 2\pi R_e \cos\left(\pi \frac{\theta_{\mathrm{lat}}}{180}\right),$$

where R_e is the radius of the Earth at the equator. The physical unit is meter/day. After conversion from days to seconds and after multiplying with the time information calculated from the sampling rate and pulse repetition interval (PRI) t_{PRI}, the phase correction factor $\vartheta_{c,e}$ for the earth rotation becomes:

$$\vartheta_{c,e} = \exp\left(j\frac{2\pi}{\lambda}\frac{v_t t_{PRI}}{24 \cdot 3600} \right),$$

where λ, is the wavelength.

The processor compresses the data in a pixel-by-pixel procedure instead of producing a raw data matrix with subsequently compressing it in range and azimuth. An empty imaging area matrix is pre-allocated with zeros and then each raw data vector for each pulse is range and azimuth compressed. Thus the imaging area matrix is filled in a serial procedure. This type of approach is considered to be suitable for real time applications.

In Figure 9, an azimuth-compressed image is shown, based on the measured data set at 28 Jan 2002.

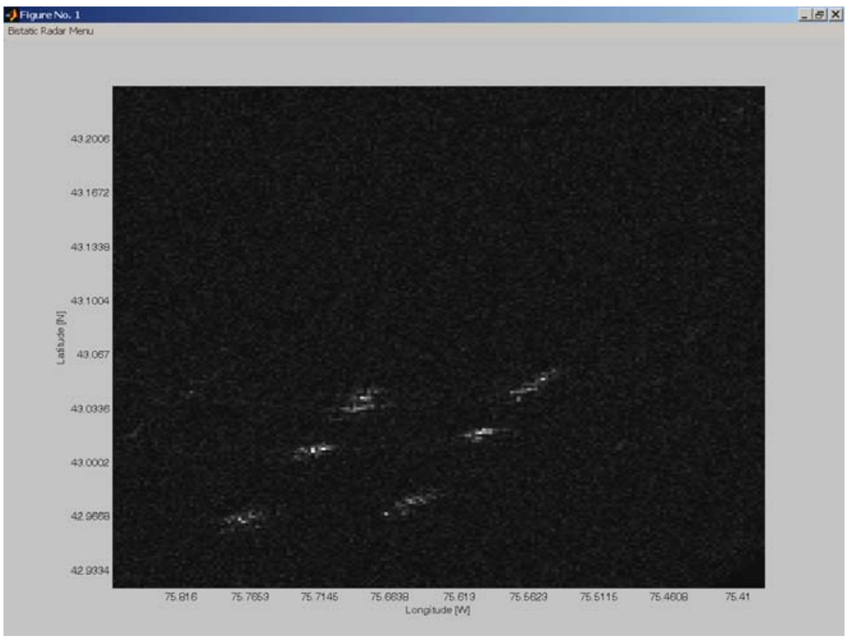

Figure 9. Azimuth compressed image

The processor is also tested using simulated data. The bistatic SAR Simulator [4] is used to produce the raw data set and a space-based geometry is chosen. The resolution of the image is found to be the same as expected and the scatterers in the image were at the chosen locations.

6. AMBIGUITY AND POST PROCESSING TOOLS

The geometry of a bistatic SAR scenario differs from that of a monostatic SAR, resulting in ambiguity problems in the final image, such as shown in Figure 9. Six clusters of scatterers are evident even though only three are correct. About one-half of the scatterers shown in the image are the result of an iso-Doppler and iso-range ambiguity. The implemented software includes a post-processing tool to examine these ambiguities in more detail. By using the `bistatic Radar menu', the equi-distance (blue) and equi-Doppler (yellow) contours can be superimposed on the SAR image, as shown in Figure 10. As evident in this figure, there are two intersection points for each iso-Doppler and iso-range contour, which are causing the ambiguities.

In Fourier transform based processors, this ambiguity problem is not observed, when the phase history for the matched filter in slow time is calculated from the measured data. But, with time domain processing, the phase history is predicted from the expected satellite locations. Therefore, certain suitable scenario geometries (quasi-forward looking) will lead to these types of ambiguities.

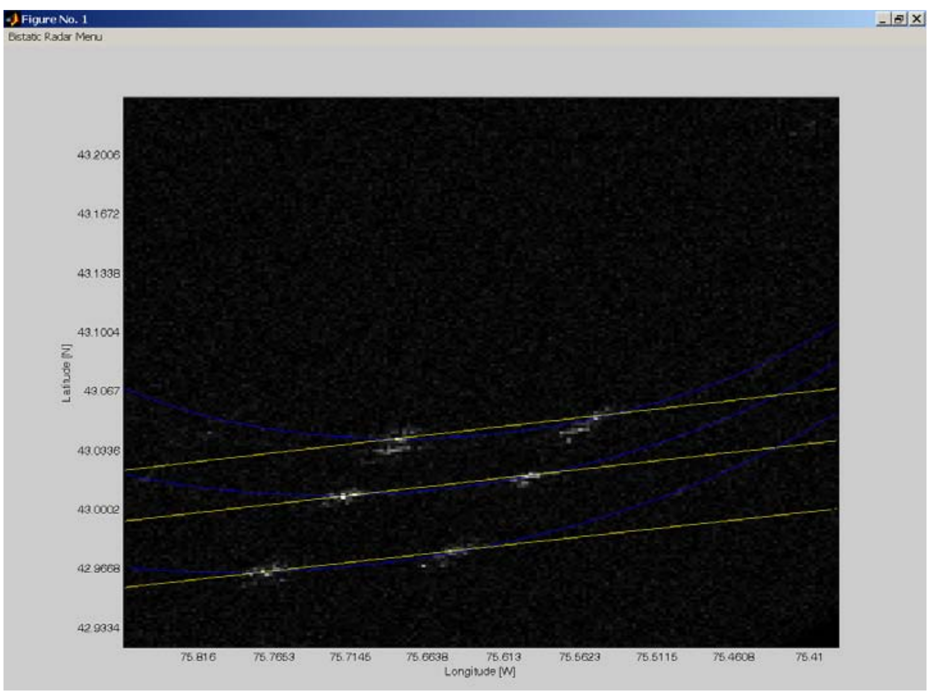

Figure 10. Equi-Distance and equi-Doppler contours superimposed on the SAR image

The processor software offers two solutions for this problem. First, there are two post-processing filters, which apply either a sinc-function or an exponential function (as a model of the receiver antenna pattern) to suppress the ghost scatterers. The second alternative is not a post-processing solution, but based on the scenario file. If the fast code parameter is set to one, then the processor calculates the pixels, which are located inside the receiver beamwidth, thus eliminating the ghost scatterers. In Figure 11, an image after the application of the sinc-filter is shown; the right-hand sided ghost scatterers have disappeared.

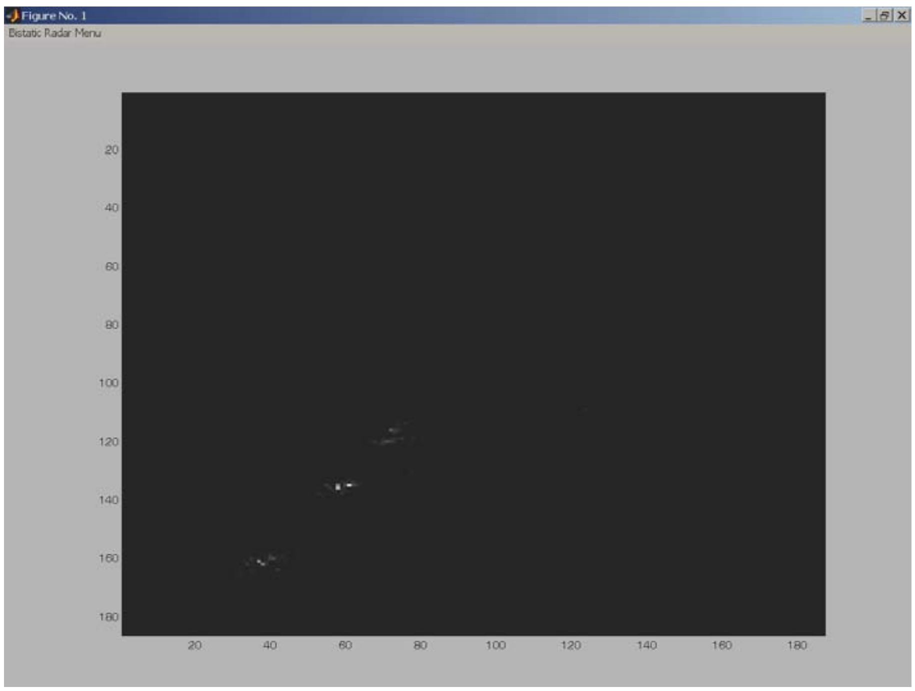

Figure 11. Image after sinc filter

The bistatic radar processor has some additional post-processing tools, such as the receiver antenna location, which is plotted in the image. These post-processing tools are listed in the menu shown in Figure 12.

The bearing of a scatterer from the receiver antenna can be calculated and plotted via the ‘bearing from North’-tool. The bearing of any selected scatterer is then plotted in the lower left corner of the image, as demonstrated in Figure 13.

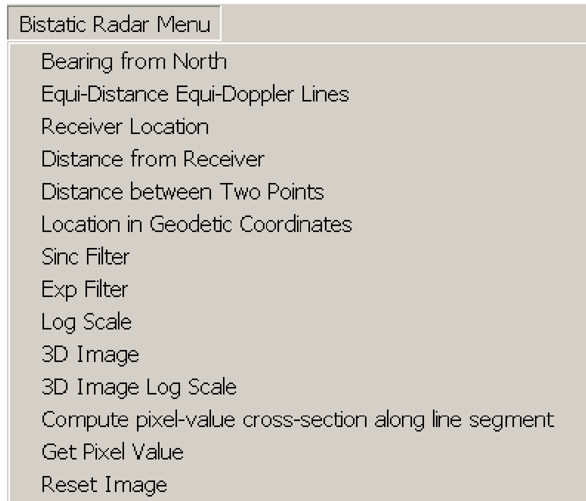

Figure 12. Post Processing Tools

The distance of the chosen scatterer from the receiver location or the distance between two selected scatterers can also be displayed in the lower left corner of the window. Further, the processor also offers a tool to display the location of a chosen scatterer in geodetic coordinates. The geodetic coordinates are shown at the lower right corner of the image. The functions for the sinc- and exp-filters have already been discussed above.

The logarithmic or 3-dimensional display of an image sometimes contains more information than the regular 2-dimensional plot. The processor includes tools to display the image in logarithmic scale, 3-dimensionally, and as a 3-dimansional image in logarithmic scale. As an example, the 3-dimansional plot of the 28 Jan 2002 data set is shown in Figure 14.

It is also possible to compute the intensity values along a line in the image by using the ‘Compute pixel-value cross-section along line segment’-tool. This post-processing tool selects equally spaced points along the path specified by the operator, and then uses interpolation to find the intensity value for each point. Figure 15 shows the scattering on a line from receiver to the lower left corner of the image.

The ‘Get Pixel Value’-tool turns on an interactive display of information about image pixels in the current figure. ‘Get Pixel Value’ installs a black bar at the bottom of the figure, which displays the Geodetic coordinates for the particular pixel the cursor is currently over. It also displays the intensity information for that pixel.

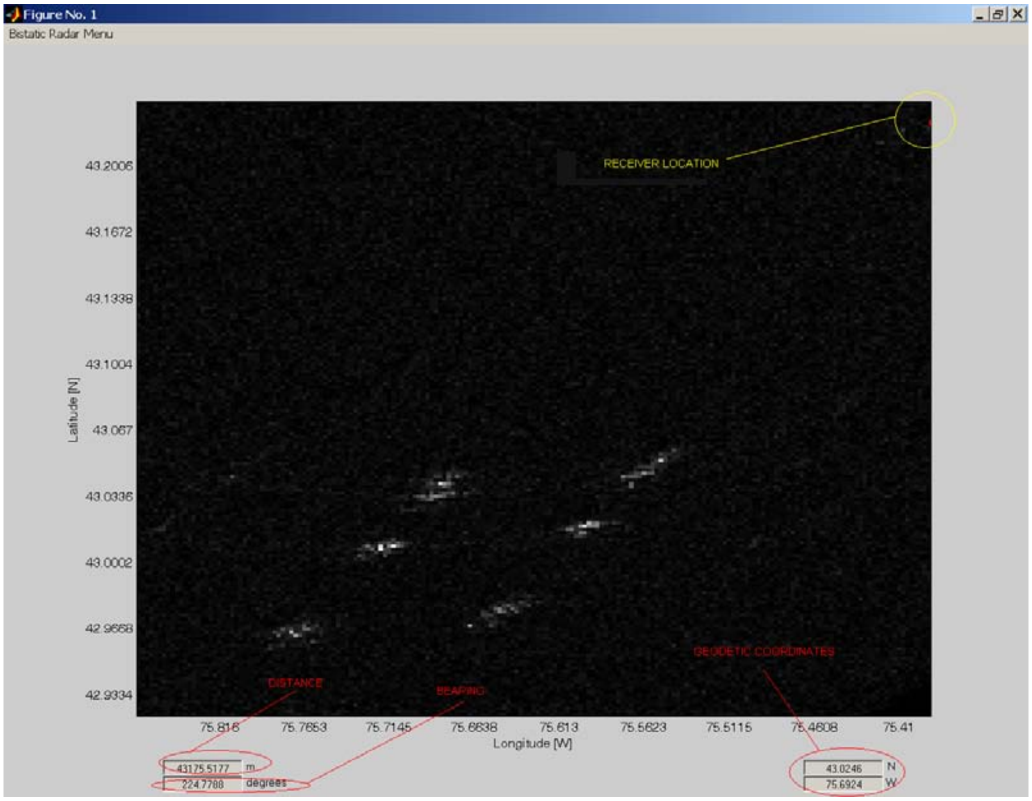

Figure 13. Post Processing Tool Boxes

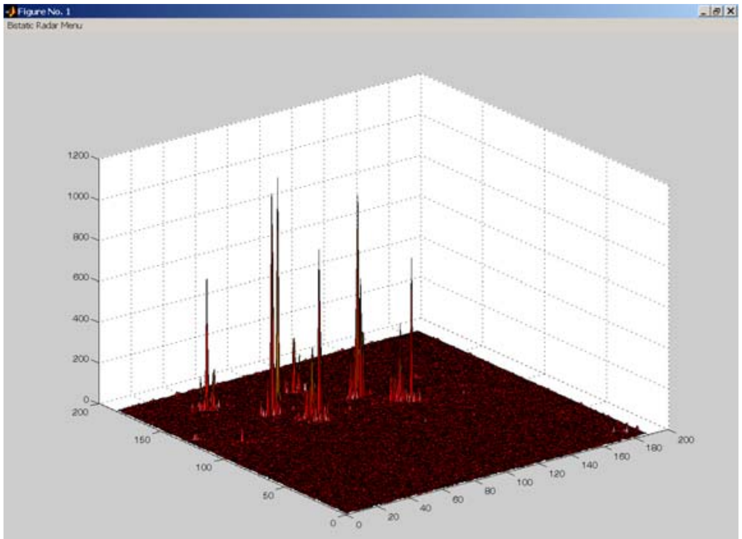

Figure 14. Three-dimensional image

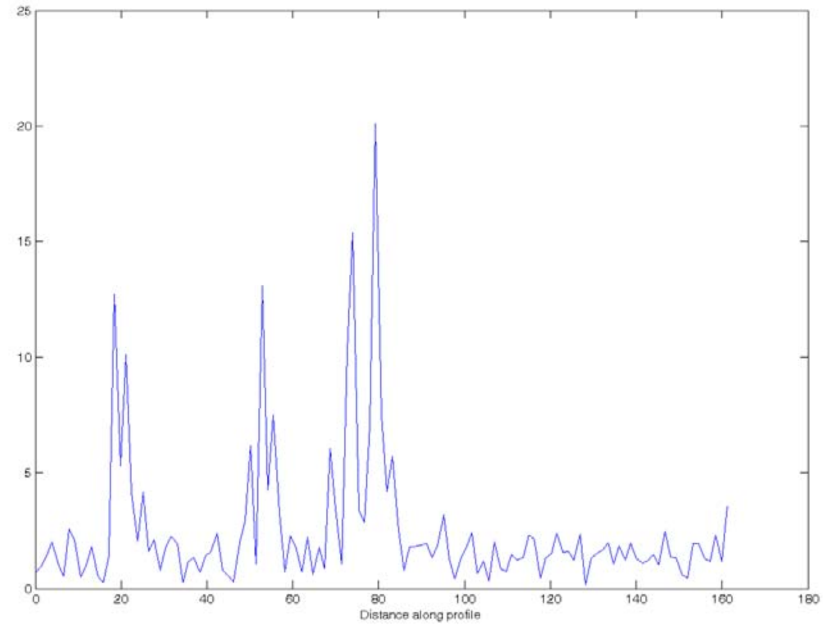

Figure 15. Example plot for scattering on a line

7. CONCLUSIONS

The time-domain SAR processor implementation in Matlab© has shown that this approach has potential for bistatic SAR applications, and also that the images produced by this approach contain valuable information. The main drawback of this approach is the processing time. For instance, it takes approximately 28 seconds on a conventional PC Pentium 4, 2.5 GHz with 1 GByte RAM, to process an image consisting of 187x187 pixels, which corresponds to only 200 satellite locations and range profiles of 16384 range bins. An increase in number of pixels affects the processing speed cubically.

In order to enhance the computational speed, the algorithm should be coded in higher languages, such as C or C++ as a first step. Additionally, modern and sophisticated algorithms for bistatic SAR processing must be developed to reduce the computational load. Unlike monostatic SAR the kernel function for bistatic cases is non-separable, and, hence, the use of fast operators (such as the Fast Fourier Transform (FFT) [5]) are prevented. Recently, Ender [6] has started to explore the theoretical background of bistatic Doppler compression and has proposed numerical methods to separate the kernel.

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Annex A : Sample Scenario File

```
% Scenario Parameters
% Stockbridge
% 28 Jan 2002

fs = 80e6;                                    % Sampling rate (samples/s)
pulsedur = 42e-06;                            % Pulse duration (s)
Bw=11.56e6;                                   % Bandwidth (Hz)
fc=20e6;                                      % Subcarrier frequency (Hz)
prf=1289;                                     % Hz
lambda=0.0566;                                % 5.3 GHz

direct_channel_file='c:\MATLAB6p5\work\28 jan 2002\ch2s5.dat';
sub_file='c:\MATLAB6p5\work\28 jan 2002\ch1s5.dat';

% if you want to browse and choose the direct & sub channel files,
% Uncomment the following
%
% [filename, pathname] = uigetfile('*.dat', 'Choose Direct Channel File');
% direct_channel_file= fullfile(pathname,filename);
% [filename, pathname] = uigetfile('*.dat', 'Choose Sub Channel File');
% sub_file= fullfile(pathname,filename);

                              % imaging area ; stockbridge 40 km;
LatStart=43.234;              % Image area (N) ; higher Latitude
LatEnd=42.9;                  % Image area (N) ; lower Latitude
LonStart=75.41;               % Image area (W) ; right Longitude
LonEnd=75.8668;               % Image area (W) ; left Longitude
h= 144.018;                   % meter ; all hegihts are assumed to be equal to
receiver antenna height

res=200;                      % Resolution in meters; each cell in the image will
have res*res size

% load satellite locations which are calculated by STK
% STK output is in km, convert to meters
%
load 28janxyz.txt -ascii
satloc(:,2:4)=X28janxyz(:,5:7)*1000; % km -> m
clear X28janxyz;
```

```
% receiver antenna location
AntennaLat=43.224747;               % Receiver Antenna Latitude (N)
AntennaLon=75.410263;               % Receiver Antenna Longitude (W)
AntennaH=h;                         % Receiver Antenna Height (m) MSL
Rec_Look=221.7;                     % Receiver Antenna Look Direction
% FOR LEE Rec_Look is 357.5 (El 0.2)
% FOR STOCKBRIDGE  221.7 (El 0.3)
% FOR UTICA  141.9 (El 0.2)


Receiver_Az_Bw=7;                   % Receiver antenna azimuth beam width; this is
used to create imaging area
Use_fast_code=0;                    % if equals one then just inside the beam is
calculated otherwise all pixels are calculated


Sat_samp_sep = 10e-3;               % Satellite locations sample separation (sec)
Sat_Min_ph = 5257;                  % Minimum range point in satellite locations
(sample no)
max_power_data=9746;                % maximum power point data
max_power_stk=360.34;               % (secs)maximum power point from stk ; where
azimuth 90 degrees (sensor to receiver AER)
min_range_stk=354.87;               % (secs)minimum range point from stk ;  (sensor to
receiver AER)



% If you dont know the minimum range point in STK calculated satellite
% locations, Uncomment the following
%
% [antennaXYZ(1,1),antennaXYZ(1,2),antennaXYZ(1,3)]=Geo2Cart(AntennaLat,-
1*AntennaLon,AntennaH);
% Sat2Ant=sqrt((satloc(:,2)/1000-antennaXYZ(1,1)).^2+(satloc(:,3)/1000-
antennaXYZ(1,2)).^2+(satloc(:,4)/1000-antennaXYZ(1,3)).^2); % satellite to antenna
range
% plot(Sat2Ant);
% [a,Sat_Min_ph]=min(Sat2Ant) % the minimum point location


% If you dont know the maximum power point in data
% Uncomment the following ; Subroutine fazbul also displays the transmitter antenna
pattern
%
```

```
% fazbul
%% The calculated point is wrong in case of saturation. Then look at the
%% image and try to find the maximum point
```

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The data set used to test the processor in this study were acquired in Rome, NY during the trial dated 28 January 2002. The data are examined for saturation, integrity, spectral properties and phase stability. The bistatic SAR processor is coded in Matlab using time-domain azimuth compression and bistatic SAR images are produced.

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